Weed Science, 52:797–801. 2004

Influence of method of phosphorus application on smooth pigweed (*Amaranthus hybridus*) and common purslane (*Portulaca oleracea*) interference in lettuce

Bielinski M. Santos
Corresponding author. Gulf Coast Research and Education Center, University of Florida, 5007 60th Street East, Bradenton, FL 34203; bmsantos@yahoo.com

Joan A. Dusky
William M. Stall
Horticultural Sciences Department, University of Florida, P.O. Box 110690, Gainesville, FL 32611

Thomas A. Bewick
USDA-CSREES-PAS, Mailstop 2220, Washington, D.C. 20250

Donn G. Shilling
Mid-Florida Research and Education Center, University of Florida, 2725 Binion Road, Apopka, FL 32703

Field trials were conducted to investigate the influence of P application method on the critical period of smooth pigweed and common purslane interference in lettuce. Studies were carried out in low-P histosols, where supplemental P fertilization is needed for lettuce production. Phosphorus was either broadcast or banded 5 cm beneath the lettuce rows at rates of 250 or 125 kg ha^{-1}, respectively. Seedlings of either smooth pigweed or common purslane were transplanted at a density of 16 plants per 5.4 m^2 (6-m row by 0.9 m wide). Weed interference duration was achieved by manual removal 2, 4, 6, or 8 wk after lettuce emergence and subsequently keeping the plot weed free until harvest. A weed-free control within each P regimen was also established. Marketable head number, head fresh yield, and head diameter were measured at harvest. Weed-free lettuce fresh yield was 20% higher with banded P than broadcast applications. In the weed–lettuce mixtures, the P regimen by weed removal interaction affected lettuce fresh yield and head diameter but not head number. Compared with broadcast P application, banded P extended the time needed to cause significant weed interference in lettuce by 10 d: from 24 to 34 d for smooth pigweed and from 37 to 47 d for common purslane.

Nomenclature: Common purslane, *Portulaca oleracea* L. POROL; smooth pigweed, *Amaranthus hybridus* L. AMACH; lettuce, *Lactuca sativa* L.

Key words: Critical period, interference, integrated weed management.

Phosphorus (P), an important macroelement for plants, is a relatively immobile nutrient in soils (Sample et al. 1980), including histosols, which require high P applications because soil P is mostly unavailable to crops (Hochmuth et al. 1994; Sample et al. 1980). In Florida, more than 80% of the lettuce production is concentrated in the Everglades Agricultural Area (EAA) (FASS 1998). Because most lettuce is grown in muck soils, high P rates are essential to satisfy crop requirements. However, weeds are often more competitive than crops in absorbing nutrients, particularly P, which requires a profuse root system to enhance uptake (DiTomaso 1995, Tilman 1982). Therefore, P placement in the soil plays a significant role in the extent and nature of competitive interactions between weeds and crops.

Some of the most important weeds in the EAA are common purslane and pigweeds (Dusky and Stall 1988). When allowed to interfere with lettuce, smooth pigweed and common purslane could reduce lettuce yields by 24 and 48%, respectively (Santos et al. 2003). However, the nature and extent of interference of these weeds with lettuce under different P regimens and rates is little understood. Previous research has shown that changes in P fertilization regimens could change potential lettuce yield reductions due to these two weeds (Santos et al. 1997, 1998). At the same time, public pressure to reduce use of P in agricultural fields, where potential water table pollution may occur (Windemuller et al. 1997), has prompted researchers to devise new weed management strategies. This is particularly true for lettuce fields, where typical weed control methods are hoeing and cultivation, which are expensive and may damage crop roots.

The extent of crop yield reduction that a weed causes is a function of the duration of the weed–crop interaction (Martin et al. 2001; Radosevich 1987; Zimdahl 1980). Previous studies have shown that fertilizer placement and rates have an impact on the critical period of weed interference (Alkamper 1976; Sindel and Michael 1992). For instance, Rasmussen (1995) determined that banding N or P reduced downy brome (*Bromus tectorum* L.) competition in wheat (*Triticum aestivum* L.). Fertilizer placement and rates can also affect crop biomass accumulation and yield. Izuno et al. (1995) showed that banding only 50% of the recommended broadcast P rate did not cause cabbage (*Brassica oleracea* var. *capitata* L.) yield reduction. In organic soils, Shrefler et al. (1994) found that the duration of spiny amaranth (*Amaranthus spinosus* L.) interference in lettuce increased with broadcast P, in contrast with reduced effects in banded P applications. Sanchez et al. (1990) demonstrated that banding only 33% of the recommended broadcast P maximized lettuce yield. This recommendation for soils with low-P content ($\leq$ 3.0 mg P L^{-1}) is between 200 and 250 kg P ha^{-1}. However, after continuous testing under grower conditions, banding 50% of the recommended broadcast P at planting was suggested instead of 33% (Bottcher et al. 1992; Hochmuth et al. 2002).

The influence of P fertilization regimens on smooth pigweed and common purslane length of interference in lettuce has not been reported previously. This knowledge might help researchers and growers to devise environmentally sound strategies to reduce weed population in lettuce and the control costs. Therefore, the objective of this research was to investigate the influence of method of P application

Table 1. Comparison of lettuce head fresh yield and head diameter in the weed-free controls within each phosphorus (P) fertilization regime.

Study	P application	P rate	Fresh yield[a]	Head diameter
		kg P ha^{-1}	t ha^{-1}	cm
Lettuce–smooth pigweed	Broadcast P	250	19 a	14.2 a
	Banded P	125	23 b	14.8 b
Lettuce–common purslane	Broadcast P	250	19 a	14.1 a
	Banded P	125	23 b	14.5 b

[a] Means within each lettuce–weed species study separated with *t*-Student test ($P < 0.05$). Means followed by the same letter do not significantly differ at the 5% level.

on the critical period of smooth pigweed and common purslane interference in lettuce.

Materials and Methods

The influence of initial removal times of smooth pigweed and common purslane on lettuce marketable fresh yield was assessed under field conditions at the Everglades Research and Education Center (EREC) of the University of Florida in Belle Glade, FL. Two field studies were conducted between October–December 1997 and January–April 1998. During each season, two separate experiments were conducted for each weed. The EREC soils were classified as Pahokee muck (Euic hyperthermic Lithic Medisaprist), low in P content as revealed by water-extractable P tests (3.0 mg P L^{-1}), which is too low for lettuce production (Hochmuth et al. 1994; Sanchez 1990). Average day/night temperatures were 28/17 C. Organic matter content was about 75%, as determined by dry combustion, and the soil pH was 6.3. After soil test analysis and recommendations that showed severe P deficiencies in the selected fields, two P rates (125 and 250 kg P ha^{-1}) were either broadcast throughout the whole field or banded 5 cm beneath each lettuce row. Potassium (K) was broadcast 10 d before bed pressing at a rate of 160 kg K ha^{-1}. On the basis of soil analysis and site recommendations (Hochmuth et al. 1994), application of other plant nutrients was unnecessary. During the trials, water was supplied continuously with subsurface irrigation, maintaining the water table approximately 60 cm below the soil surface (Izuno et al. 1995; Maynard et al. 2002).

Following local lettuce growing practices, two rows of 'South Bay' crisphead lettuce were directly seeded on 0.9 m-wide beds, with 30 cm between lettuce rows. One week after crop emergence, lettuce was thinned to 30 cm within row spacings. Ten days before lettuce planting, smooth pigweed and common purslane seeds were sown in styrofoam multicell trays (24 cm^3 $cell^{-1}$) and grown until they reached the two-true leaf stage, approximately 10 d after seeding. Weed seedlings (approximately 5 cm tall) of either smooth pigweed or common purslane were uniformly transplanted between the two lettuce rows at a density of 16 plants per 5.4 m^2 (6-m-long plots by 0.9 m wide). The weed density and the distribution pattern were chosen on the basis of preliminary trials and field observations that suggested that interference occurs under those conditions. Duration of interference was achieved by removing the weeds 2, 4, 6, or 8 wk after lettuce emergence. In each lettuce–weed study, there were two weed-free treatments, corresponding to each P regimen. Unplanted weeds between bed rows were removed by hoeing whereas those on the planting beds were removed by hand.

A split-plot design was used, with P regimens (250 and 125 kg P ha^{-1} for the broadcast and banded practices, respectively) as the main plots and weed removal times as the subplots. Four replications were established. The central 50% of the surface area of each experimental unit was harvested when lettuce plants in weed-free controls reached maturity on the basis of head firmness, size, and appearance (USDA 1985). Outermost wrapping leaves were removed and discarded before weighing the heads. Marketable lettuce head number, head fresh yield, and head diameter were obtained at harvest, which occurred at 60 d after the weeds were transplanted. Head diameter was measured to determine lettuce head quality. To isolate the effect of P fertilization regimens on lettuce fresh yield and head diameter, the weed-free controls within each study were compared with a Student's *t* test at the 5% significance level. Data for each lettuce–weed study were subjected to analysis of variance (ANOVA) at the 5% significance level ($P \leq 0.05$) to test for single factor effects and interactions (SAS 1990). Because no significant treatment by trial interactions were found, data from the two trials were combined for analysis purposes. Lettuce fresh yield and head diameter were expressed as percentages of the weed-free control for each P regimen. The relationship between weed removal times and each variable was described with the following logistic model,

$$y = c + d/(1 + \exp(-a + bx)) \qquad [1]$$

where y is the relative yield as a percentage of the weed-free control, x is the duration of interference, a and b are the parameters that determine the shape of the curve, and c is the lower asymptote (Halford et al. 2001; Martin et al. 2001).

Results and Discussion

Smooth Pigweed–Lettuce Studies

Phosphorus fertility regimen and removal time interactively ($P < 0.05$) affected lettuce fresh yield and head diameter but not marketable head number (data not shown). In the weed-free controls, banding P at a rate of 125 kg P ha^{-1} increased lettuce fresh yield and head diameter in comparison with the broadcast P weed-free treatment (Table 1). These differences were approximately 20 and 4% for lettuce fresh yield and head diameter, respectively. Therefore, band-

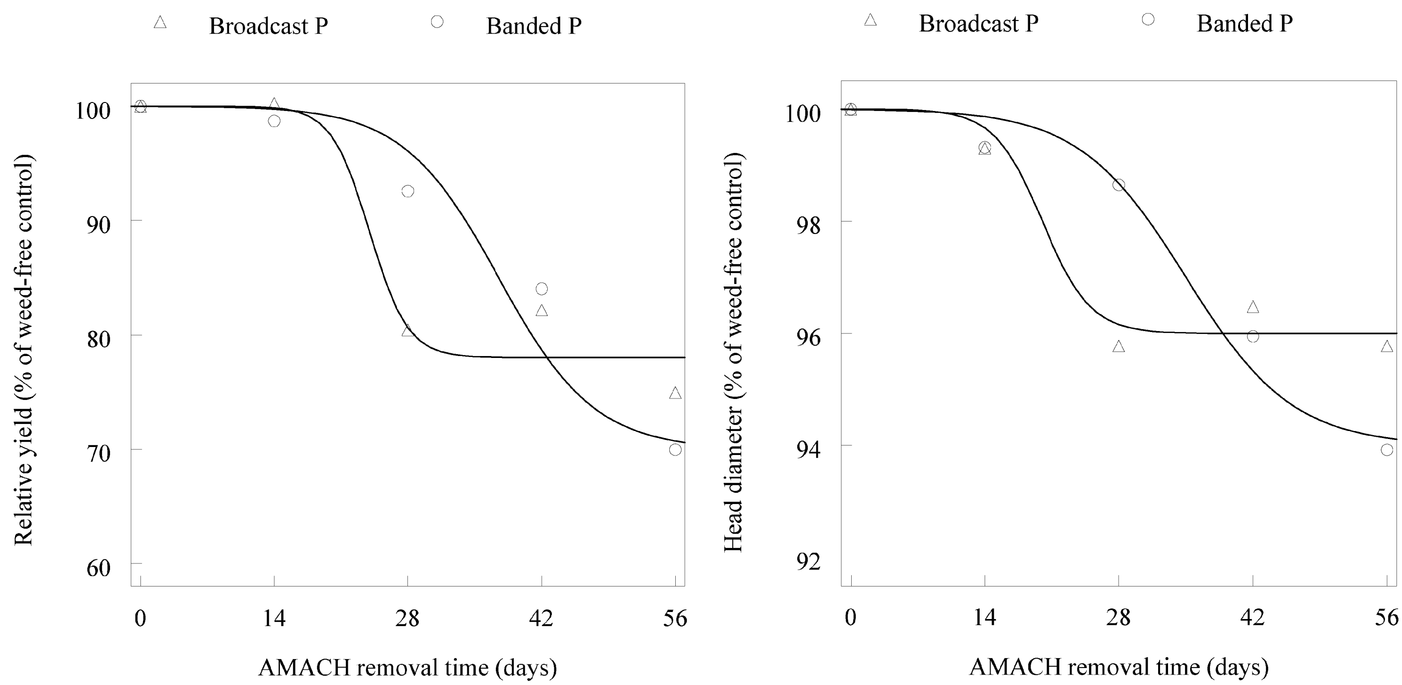

FIGURE 1. Influence of phosphorus (P) application method on smooth pigweed (AMACH) interference in lettuce: effect on lettuce relative yield and head diameter. Equations for lettuce fresh yield are: $y = 77.9 + 22.2/1 + e^{(-12+0.50x)}$, $r^2 = 0.91$; and $y = 70.2 + 30.1/1 + e^{(-7.5+0.21x)}$, $r^2 = 0.96$, for broadcast and banded P, respectively. Equations for head diameter are: $y = 94.0 + 6.3/1 + e^{(-6.3+0.18x)}$, $r^2 = 0.90$; and $y = 94.2 + 6.0/1 + e^{(-6.3+0.18x)}$, $r^2 = 0.94$, for broadcast and banded P, respectively.

ing P at 125 kg P ha^{-1} increased lettuce yield and quality in the absence of weed interference.

For lettuce fresh yield losses, two distinctive trends characterized the lettuce response as related to smooth pigweed duration of interference. For broadcast P, lettuce yield reductions remained relatively unchanged for 14 d after transplanting (DAT). However, there was a rapid decrease in yield between 14 and 28 DAT, which stabilized thereafter. The fitted logistic equation for broadcast P was $y = 77.9 + 22.2/1 + e^{(-12+0.50x)}$. The highest predicted lettuce yield loss reached approximately 22% at 28 DAT. In contrast, lettuce yield reduction under banded P declined slowly with time (Figure 1). The equation $y = 70.2 + 30.1/1 + e^{(-7.5+0.21x)}$ represented the relationship between smooth pigweed removal time and lettuce yield loss. Within this P regimen, maximum yield loss was about 30% at 56 DAT. As reflected by the r^2 values, both equations explained the majority of the variability (91 and 96% for broadcast and banded P, respectively) of the studies within the range of length of interference tested. On the basis of the regression equations for each P regimen and considering a critical fresh yield loss of 5%, this level is predicted to occur at 24 DAT in the broadcast P trials, whereas this period increased to 34 DAT in the banded P situations.

For lettuce head diameter, the equation for broadcast P was similar to that for lettuce fresh yield, with no significant changes during the first 14 d, dropping abruptly for the next 14 d (Figure 1). This decline in head diameter represented approximately 4% at 28 DAT. No change was observed thereafter. For banded P, head diameter decreased slowly, with a maximum reduction of about 6% at 56 DAT. The regression equation for lettuce head diameter in broadcast and banded P were $y = 94.0 + 6.3/1 + e^{(-6.3+0.18x)}$ and $y = 94.2 + 6.0/1 + e^{(-6.3+0.18x)}$, respectively. In both cases, the models explained 90 and 94% of variability. If a critical head diameter reduction of 2% is assumed, the smooth pigweed removal time increased from 20 to 35 DAT when banded replaced broadcast P. Because the number of marketable lettuce heads was not affected by removal time of this weed, the effect of duration of smooth pigweed interference on the crop was manifested as weight reduction of individual lettuce heads. This is an indication of quality reduction because small lettuce heads will have reduced head diameters caused by diminished fresh yield. Under the conditions of these experiments, banded P at 125 kg ha^{-1} resulted in enlarged head diameters within each removal time compared with broadcast P treatments.

These findings suggest that banding P may have three distinctive benefits. First, banding P reduced the negative impact of smooth pigweed interference on lettuce by lengthening the time frame before control measures must be implemented. This situation might provide lettuce growers with more schedule flexibility for weed management. Second, it appears that banding P gives lettuce an additional advantage to absorb necessary P amounts before smooth pigweed interference becomes critical. This indication is suggested by the fact that in the weed-free treatments, lettuce produced more with banded than with broadcast P. Finally, the results confirmed that P rates could be reduced by 50% without affecting the crop, with the consequent environmental benefit of less groundwater P pollution.

Common Purslane–Lettuce Studies

There was significant P fertility regimen by common purslane removal time interaction ($P < 0.05$) observed for lettuce fresh yield and head diameter. The number of marketable lettuce heads per treatment was not affected by ei-

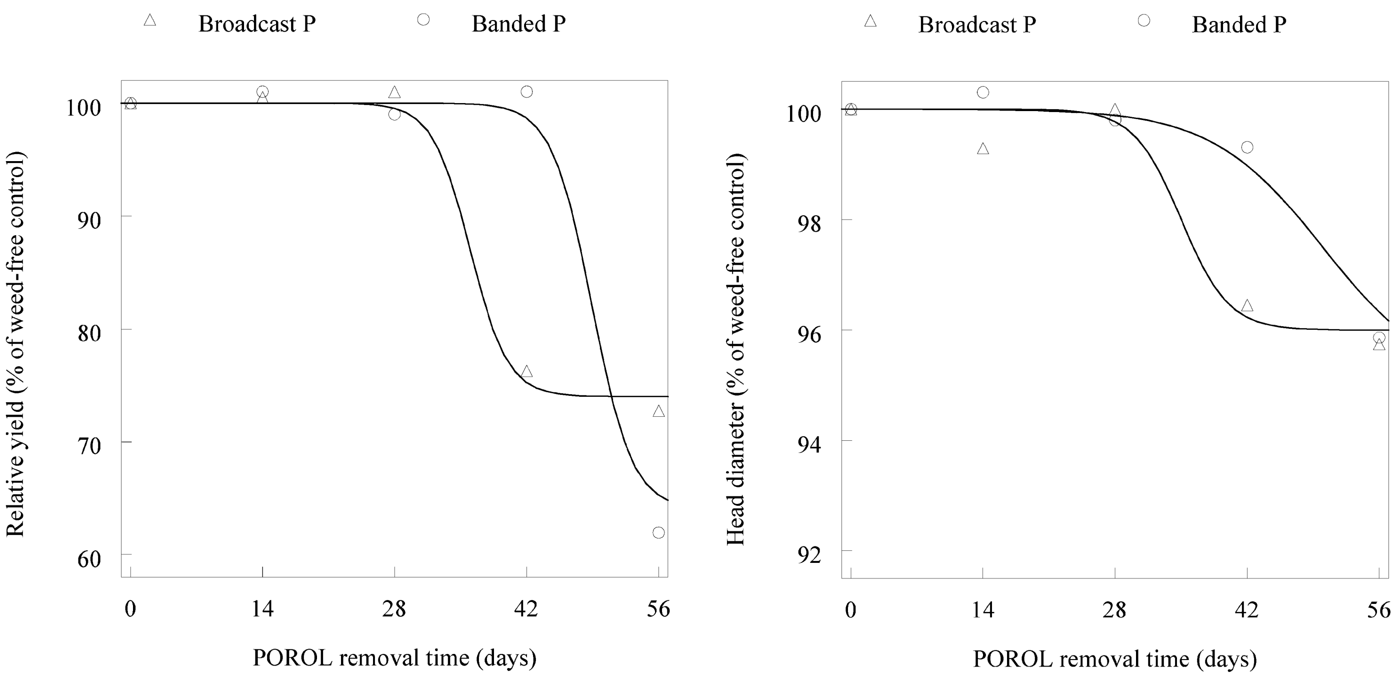

FIGURE 2. Influence of phosphorus (P) application method on common purslane (POROL) interference in lettuce: effect on lettuce relative yield and head diameter. Equations for lettuce fresh yield are: $y = 73.8 + 25.9/1 + e^{(-17.9+0.47x)}$, $r^2 = 0.90$; and $y = 64.3 + 35.9/1 + e^{(-22.9+0.45x)}$, $r^2 = 0.88$, for broadcast and banded P, respectively. Equations for head diameter are: $y = 96.4 + 3.9/1 + e^{(-14.1+0.42x)}$, $r^2 = 0.91$; and $y = 96.7 + 5.2/1 + e^{(-8.5+0.17x)}$, $r^2 = 0.93$, for broadcast and banded P, respectively.

ther P fertility regimens or removal times (data not shown). In the weed-free situations, lettuce head fresh yield and head diameter were 19 and 3% higher when banding 125 kg P ha^{-1} than with the broadcast P rate (Table 1).

Both P regimens caused no significant changes in common purslane duration of interference during the first 28 d (Figure 2). However, between 28 and 42 DAT, there was a 27% decrease in lettuce fresh yield in the broadcast P situation. This level of yield reduction remained unchanged for the rest of the season. In contrast, the banded P treatments did not cause fresh yield changes up to 42 DAT, but yield dropped sharply thereafter. The relationship between common purslane removal time and lettuce fresh yield was described by the equations $y = 73.8 + 25.9/1 + e^{(-17.9+0.47x)}$, and $y = 64.3 + 35.9/1 + e^{(-22.9+0.45x)}$, for broadcast and banded P, respectively. If a critical yield loss of 5% were assumed, this level would be reached at 37 and 47 DAT for broadcast and banded P, respectively.

No significant lettuce head diameter reduction due to common purslane interference was observed during the first 28 d, regardless of the P regimen used (Figure 2). However, after 28 DAT, the two regression curves expressed differently the relationship between head diameter losses and common purslane removal times. Whereas the curve for broadcast P declined abruptly between 28 and 42 DAT, the one for banded P showed a negligible change during this period. The highest head diameter loss due to season-long interference of common purslane reached approximately 4% for both P regimens. If a critical head diameter reduction of 2% is considered, the common purslane length of interference increased from 35 to 50 DAT when banded replaced broadcast P. As observed in smooth pigweed, common purslane interference reduced lettuce fresh yield and head diameter, without affecting the number of commercial heads produced. Banding P increased yield and quality in comparison with broadcast P treatments.

The results indicate that modifications in P fertilization practices, including P rate reductions, altered the critical period of interference of both weeds. These findings along with others previously reported (Santos et al. 1997) support the theory that banding P changes the nature of the competitive interactions of smooth pigweed–lettuce and common purslane–lettuce associations to the advantage of the lettuce crop. There are two possible explanations for the increased time frame necessary to reduce lettuce yield: (1) banding concentrated P closer to the lettuce rooting system, causing an increase in lettuce competitiveness, therefore reducing the negative impact of the weeds, and (2) banding allowed lettuce to absorb larger P amounts at early stages before weed roots extended to the nutrient location. These results agree with those described by Rasmussen (1995) and Shrefler et al. (1994), where banding fertilizer lengthened the time frame necessary for weeds to reduce yield in comparison with broadcast treatments. Further studies should focus on determining the specific mechanisms of interference of these weeds on lettuce as affected by P rates.

Acknowledgment

Published as Florida Agricultural Experiment Station Journal Series R-09200.

Literature Cited

Alkamper, J. 1976. Influence of weed infestation on effect of fertilizer dressings. Pflanzen.-Nachr. Bayer 29:191–235.

Bottcher, D., E. Hanlon, and F. Izuno. 1992. Fertility best management practices for phosphorus control on organic soils: banding fertilizer.

Florida Cooperative Extension Service Bull. AGR-53. Gainesville, FL: IFAS. 4 p.
DiTomaso, J. M. 1995. Approaches for improving crop competitiveness through the manipulation of fertilization strategies. Weed Sci. 43:491–497.
Dusky, J. A. and W. M. Stall. 1988. Evaluation of herbicides for weed control in Florida lettuce production. Proc. Fla. State Hortic. Soc. 101: 367–370.
[FASS] Florida Agricultural Statistics Service. 1998. Florida Agricultural Statistics: Vegetables Summary 1997–1998. Tallahasee, FL: Florida Department of Agriculture and Consumer Services. 64 p.
Halford, C., A. S. Hamill, J. Zhang, and C. Doucet. 2001. Critical period of weed control in no-till soybean (*Glycine max*) and corn (*Zea mays*). Weed Technol. 15:737–744.
Hochmuth, G., E. Hanlon, R. Nagata, G. Snyder, and T. Schueneman. 1994. Crisphead lettuce: fertilization recommendations for crisphead lettuce grown on organic soils in Florida. Florida Cooperative Extension Service Bull. SP-153. Gainesville, FL: IFAS. 25 p.
Hochmuth, G., R. Rice, and E. Simonne. 2002. Phosphorus management for vegetable production in Florida. Florida Cooperative Extension Service Bull. HS-105. Gainesville, FL: IFAS. 4 p.
Izuno, F. T., A. B. Bottcher, F. J. Coale, C. A. Sanchez, and D. B. Jones. 1995. Agricultural BMPs for phosphorus reduction in south Florida. Trans. ASAE 38:735–744.
Martin, S. G., R. C. van Acker, and L. F. Friesen. 2001. Critical period of weed control in spring canola. Weed Sci. 49:326–333.
Maynard, D. N., G. J. Hochmuth, C. S. Vavrina, W. M. Stall, T. A. Kucharek, and S. E. Webb. 2002. Lettuce, endive, escarole production in Florida. Pages 195–202 *in* S. O. Olson and D. N. Maynard, eds. Vegetable Production Guide for Florida, 2002–2003. Gainesville, FL: IFAS.
Radosevich, S. R. 1987. Methods to study interactions among crops and weeds. Weed Technol. 1:190–198.
Rasmussen, P. E. 1995. Effects of fertilizer and stubble burning on downy brome competition in winter wheat. Commun. Soil Sci. Plant Anal. 26:951–960.
Sample, E. C., R. J. Soper, and G. J. Racz. 1980. Reactions of phosphate fertilizers in soils. Pages 263–304 *in* F. E. Khasawneh, ed. The Role of Phosphorus in Agriculture. Madison, WI: ASA, CSSA, SSSA.
Sanchez, C. A. 1990. Soil-testing and fertilization recommendations for crop production on organic soils in Florida. Florida Cooperative Extension Service Bull. Gainesville, FL: IFAS. 876.
Sanchez, C. A., S. Swanson, and P. S. Porter. 1990. Banding P to improve fertilizer use efficiency of lettuce. J. Am. Soc. Hortic. Sci. 115:581–584.
Santos, B. M., J. A. Dusky, W. M. Stall, and D. G. Shilling. 1997. Influence of smooth pigweed and common purslane densities on lettuce yields as affected by phosphorus fertility. Proc. Fla. State Hortic. Soc. 110: 315–317.
Santos, B. M., J. A. Dusky, W. M. Stall, D. G. Shilling, and T. A. Bewick. 1998. Phosphorus effects on competitive interactions of smooth pigweed (*Amaranthus hybridus*) and common purslane (*Portulaca oleracea*) with lettuce (*Lactuca sativa*). Weed Sci. 46:307–312.
Santos, B. M., J. A. Dusky, W. M. Stall, D. G. Shilling, and T. A. Bewick. 2003. Influencia de la fertilización fosforada sobre la interferencia de *Amaranthus hybridus* y *Portulaca oleracea* en lechuga producida en suelos orgánicos. Manejo Integrado Plagas Agroecol. 67:13–17.
[SAS] Statistical Analysis System. 1990. SAS Procedures Guides. Version 6, 3rd ed. Cary, NC: Statistical Analysis Systems Institute. 567 p.
Shrefler, J. W., J. A. Dusky, D. G. Shilling, B. J. Brecke, and C. A. Sanchez. 1994. Effects of phosphorus fertility on competition between lettuce (*Lactuca sativa*) and spiny amaranth (*Amaranthus spinosus*). Weed Sci. 42:556–560.
Sindel, B. M. and P. W. Michael. 1992. Growth and competitiveness of *Senesio madagascariensis* Poir. (fireweed) in relation to fertilizer use and increases in soil fertility. Weed Res. 32:399–406.
Tilman, D. 1982. Resource Competition and Community Structure. Princeton, NJ: Princeton University Press. 578 p.
[USDA] United States Department of Agriculture. 1985. United States Standards for Grades of Lettuce. Washington, D.C.: Agricultural Marketing Service. 125 p.
Windemuller, P., D. L. Anderson, R. H. Aalderink, W. Abtew, and J. Obeysekera. 1997. Modeling flow in the Everglades Agricultural Area irrigation/drainage canal network. J. Am. Water Resour. Assoc. 33:21–34.
Zimdahl, R. L. 1980. Weed-crop competition: A review. Corvalis, OR: International Plant Protection Center, Oregon State University. 175 p.

Received May 8, 2003, and approved March 12, 2004.